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FLEXURAL BEHAVIOR OF SPLICED ULTRA HIGH STRENGTH CONCRETE BEAMSUSING FINITE ELEMENT ANALYSIS

Ahlam Sader Mohammad
Building and Construction Engineering Department, University of Technology, Baghdad, Iraq
E-Mail: ahlamsader@yahoo.com

ABSTRACT

This paper is an analytical study of spliced ultra high strength concrete (UHSC) beams using finite element analysis to predict their load-deflection response. Two UHSC beams model was generated and analyzed by ANSYS15 and the results compared with the experimental results as a verification process. The resulted load deflection curve from the analytical work compared well to experimental results. The average difference between the two works was 98% in failure load results, and it was 85% in deflection results. A parametric study was then performed by modeling and analyzing another three non spliced and six spliced UHSC beams with three different steel fiber volumetric ratios (1.5% 1%, and 0.5%) and two different lap splice lengths (10 and 15 times diameter of bar). The obtained analytical results indicated that the volumetric steel fiber ratio has significant effect on the adequate lap splice length in UHSC beams.

Keywords: lap splice, ultra high strength concrete, ANSYS15 program, steel fiber volumetric ratio.

1. INTRODUCTION

Experimental method has been widely used to study the effects of different parameters on the concrete structural elements behavior. The use of finite element analysis to study these components has also been used and has been preferred method to study the behavior of concrete (for economic reasons). The earliest analytical research of lap splice in normal concrete by finite element method was introduced by Axlsson and Fröier *1971*[1], Eligehausen *1979*[2] Tocci *et al 1981*[3], and Panashahi *et al 1987*[4]. In recent years, however, the use of finite element analysis has increased due to progressing knowledge and capabilities of computer software and hardware. It has now become the choice method to analyze concrete structural components, because the use of computer software to model these elements is much faster, and extremely cost-effective. Ali 2001[5] presented two methods for the analysis of spliced reinforced concrete beams to predict their global and local behavior. In the first method, a three dimensional finite element technique was performed for the global analysis. While in the second method, a one dimensional elastic- plastic analytical model was introduced to trace the local behavior. Adequate agreement between experimental and analytical load deflection behavior results was obtained with an overestimation in the ultimate load in between 20% and 40%. Ogura *et al 2007* [6] studied analytically, the influence of lateral reinforcement, concrete strength and the positioning of the main reinforcing bars on the development of bond splitting failure in reinforced concrete. The results showed, along with radial opening displacement of the concrete due to slippage of the main reinforcing bars, compressive stress is transferred from the steel to the concrete. Ali and Hussein 2013[7] performed an experimental and theoretical investigation for behavior of reinforced concrete beams with tensile reinforcement lap splices strengthened by CFRP laminates. Then a comparison between the results of the two methods was carried out to confirm the modeling adequacy of elements, material properties and real constant in predicting the response of R.C beams containing tensile reinforcement lap splices with or without strengthening. ANSYS computer program (version 9.0, 2004) was performed throughout this study. The results obtained from F.E analysis gave good agreement when compared with the experimental results which include, ultimate load, cracking load, maximum deflection and mode of failure. From the reasonable agreement and accuracy of the finite element model with experimental results, a parametric study was performed included effect of wrapping shape of CFRP sheet and diameter of reinforcing spliced bar parameters on beams containing tensile reinforcement lap splices. Ali *et al 2016* [8] performed study about Nonlinear Analysis of Spliced Continuous reinforced concrete Girders Strengthened with (CFRP) Laminates using ANSYS. Five spliced continuous girders and one non-spliced continuous girder were analyzed using the ANSYS program. The ANSYS model succeeded to an acceptable degree in predicting the structural behavior of the analyzed spliced girders with average of differences of about 6% between the predicted and experimental ultimate load. This review of past efforts and contributions related to F.E most closely related to the needs of the present work.

Because UHSC is a relatively new and the researches concern with are in progress, there is a lack of information from both codes requirements or experimental researches which related to lap splice in this type of concrete. This cause inevitable to predict the UHSC elements behavior using the finite element analysis and that will give better understanding about the structural behavior of such elements and thereby optimize the design for structural efficiency and economy. The objective of this research is to investigate and predict the load deflection response of spliced UHSC beams by a commercial finite element analysis package (ANSYS15) using experimental data. This experimental data will be taken from Lee 2015[9] since he studied experimentally the bonding behavior of lap-spliced reinforcing bars embedded in UHSC.

Based on the results obtained from the analysis modeling parameters set by this model and the agreement with the experimental results of the selected two beams (UC-2-N) and (UC-2-10db) from *Lee 2015* [9], the validity of utilizing ANSYS 15 in modelling UHSC beams would be assured. The parameters of this modeling were then be used to model the other beams with three steel fiber ratios. Both beams had a cross-section of (150 × 250) mm and a length of 2.0m. The geometry and beam designation of these beams are presented in Figure-1.

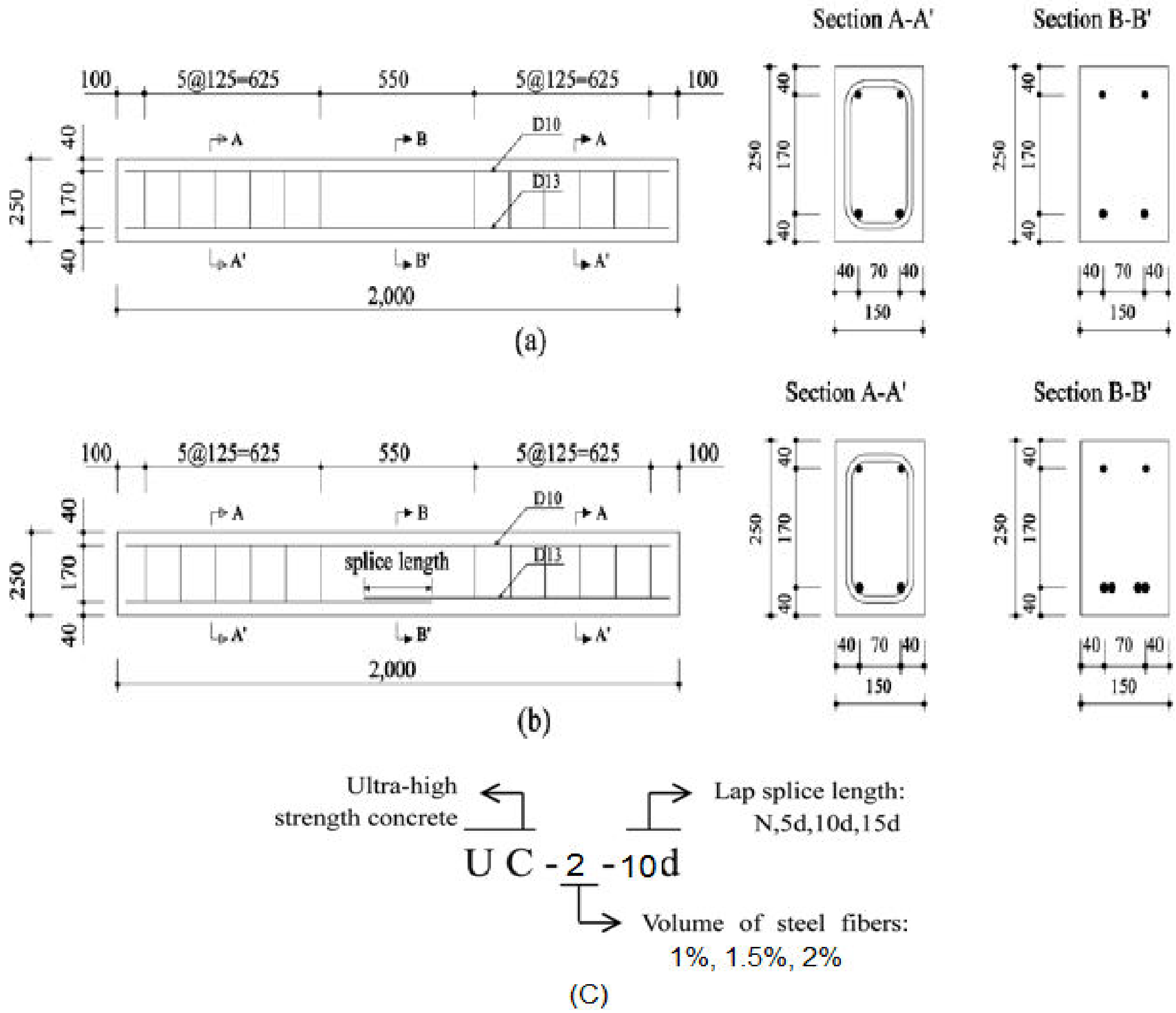

Figure-1. Geometry and details of the UHSC beam specimens (a) UHSC beam specimen, (b) Lap-spliced UHSC beam specimen, (c) Designation of the UHSC beam specimen.

The diameter of the bottom (tension) reinforcement bars was13mm, while it was 10mm for the top (compression) reinforcement bars, and the concrete cover was 2.5 times diameter of bar, or 33 mm. The position of the tension lap-spliced bars was at the mid-span of the beam without stirrups reinforcement within this region. The tested compressive strength of these beams using Φ100 × 200 mm cylinders was 135 MPa at the age of the tested day and the modulus of elasticity was equal to 43,000 MPa. A straight type of steel fiber was used in the experiments with length of 12 mm and a diameter of 0.5 mm whereas the ultimate strength equal to 1, 110 MPa. The reinforcing bar type was uncoated deformed steel bar and the measured yield strength and ultimate strength were 500 MPa and 600 MPa, respectively and the measured elastic modulus was 190,000 MPa.

2. DETAILS OF STUDIED BEAMS

Only two of the UHSC beams which were tested experimentally by Lee 2015 were analyzed first using ANSYS15 computer program as a verification models in the present study. One beam without spliced bottom reinforcement bars (UC-2-N) and the other beam with spliced bottom reinforcement bars (UC-2-10db). Designations of the studied beams were presented in relation to the length of lap splice and the volumetric amount of steel fibers as summarized ins Table-1.

Table-1. Beams designations.

Beams	Lap splice		Vf%	Remarks	
	Length (mm)	**Ls/db**			
UC-2-N	-	-	2	without splice	Verification models
UC-2-10db	130	10	2	Spliced beam	

3. FINITE ELEMENT ANALYSIS

This section speaks about the verification of the FE modeling by comparing the analytical results with the experimental load-deflection response results of a UHSC beam sexist in Lee 2015[9]. This study used the computer software ANSYS version 15 to model the UHSC beams with the corresponding dimensions and properties from the experimental results. Each necessary step which required generating these models are explained in details as well as the steps to draw the analytical load-deflection behavior of the members.

3.1 ANSYS finite element model

The FEA verification study consisted of generating two UHSC beams UC-2-N and UC-2-10d tested by Lee (2015) [9] with their dimensions and materials properties. The existence of the lap splice prevented utilizing the symmetry advantages (disk store and time saving) as a result each beam was modeled with its whole dimensions .Two methods provided in ANSYS program to create the members and that are the command prompt line input or the graphical user interface. For this model, the first method was used in this study. The following items illustrate the different tasks and entries used to generate the FE verification model.

3.1.1 Element types

Solid65 Element: This8- node brick element which was used to model the UHSC has plastic deformation ability, cracking in three orthogonal directions and crushing. Extensively the properties of concrete components (mainly cement mortar, aggregates and air voids) affect concrete behavior. Steel fiber volume ratio, shape of fibers, the uniformity of fiber distribution and surface conditions of the fiber are additional effective variables in case of UHSC included steel fibers. The smeared model was used to represent the steel fibers in the UHSC matrix, as this model assumes that reinforcement is uniformly distributed within the concrete in the defined region of finite element (Figure-2).

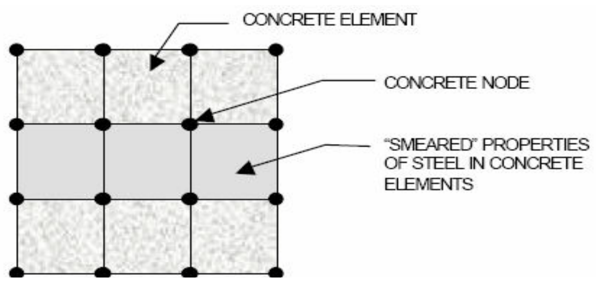

Figure-2. S smeared modal for steel fiber [10].

Link 180 elements were adopted to model the steel reinforcement bars. This element has two nodes with three degrees of freedom in the X, Y and Z direction translations at each node and capable of plastic deformation. Discrete representation to represent the reinforcement steel bars has been widely used due to its capability to adequately account for the bond-slip and dowel action phenomena as seen in Figure-3. As a result, it was used in this analysis to connect the steel bars elements to the concrete mesh nodes. Consequently, both concrete and steel bar mesh share the same nodes, with one exception in the region of lap splice and this will be discussed later inCombin39 element item.

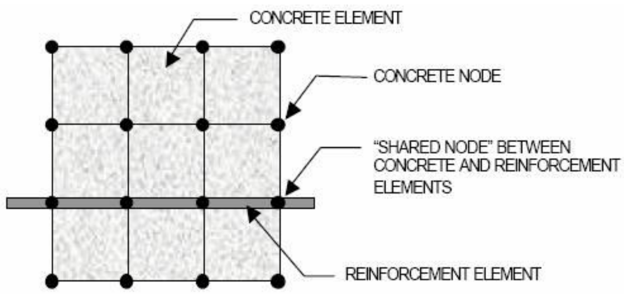

Figure-3. Discrete model for steel bars [10].

The bond- slip relationship idealization between UHSC and the reinforcement bars within the region of lap splice was performed by using nonlinear spring combine 39 element this element is a nonlinear unidirectional element which can be used for torsion or longitudinal capability in one, two or three dimensional. To idealize the bar slippage with respect to UHSC the longitudinal option in X- direction was adopted within this work. This element is zero length elements, since it was created by two coincident nodes.

3.1.2 Material properties

There are multiple parts of the material model for each element. The UHSC which marked as material number 1, the program (ANSYS) impose input data to the properties of material for proper entities. The terms that need to be determined were tabulated in Table-2.

The value of the modulus of elasticity for UHSC was 43000MPa as obtained from the experimental work, while Poisson's ratio (ν) was assumed to be 0.2.The shear strength reduction coefficients for opened crack case (β_o) value varied between 0-1. It was noticed that changing the value of this coefficient did not deviate results [11], so β_o was taken as 0.65.While$\beta_c$the shear strength reduction coefficients for closed crack case was set as 0.9 according to [12]. The tensile strengths of UHSC adopted in this work were $0.4\sqrt{f'_c}$(according to Tama [13]). The compressive strength (f'_c) value was taken from the experimental work results and it was 135Mpa.

Material model number 2 represents the steel fibers which had assumed Poison's ratio and modulus of elasticity equal to 0.3 and 200000MParespectively.

The material number 3 has the characteristics of the bottom reinforcement bars while material number 4relates to both top reinforcement bars and stirrups steel bars. The yield strength (f_y) of all steel bars were measured to be 500MPa and modulus of elasticity E_s= 190000MPaaccording to the experimental work and assumed Poisson’s ratio v_s=0.3.

3.1.3 Real constants

Each element type needs its own real constants which have to be entered as data relate to this element as it will be mentioned below:

In fact the real constants of Solid 65 element do not relate to this element directly, but to the steel fibers (material number 2) which modeled as a smeared modeling in this element as mentioned before. The steel fiber: material number, volumetric ratio, and orientation angle should be filled in the fields of real constants. The value of volumetric ratio (2%) should be divided by 3 to represent the uniformly distributed of these steel fibers within the concrete matrix as listed in Table-3.

Link180 element: The cross sectional area of each bar needs to be entered for this element as real constants. There are two different bars in each beam, so the real constant number 2 will represent the 13mm diameter bottom bar and real constant number 3 relates to top and stirrups bars which has 10mm diameter in each beam.

The values of real constants of both the above two elements (Solid 65 and Link180) were gathered in Table-2.

Table-2. Real constants of Solid65 and Link180 elements.

Real constant set	Element type	Properties		Real constants		
				rebar1	rebar2	rebar3
1	SOLID65	Material number		2	2	2
		Volume ratio	2.0%	0.0067	0.0067	0.0067
		Orientation angle THETA(horizontal angle)		0	90	0
		Orientation angle PHI (Vertical angle)		0	0	90
2	LINK180	Cross-sectional area(mm2) - Ø 12 mm		133		
3	LINK180	Cross-sectional area (mm2) -Ø10mm		78.5		

Combin39 element: The real constant of this element should be entered in a table form which listed the values of slip (mm unit) and force (N unit). These values represent the local bond stress - slip relationship between the steel reinforcement bar and concrete matrix surrounding it which are resulted from pullout tests performed on bar embedded in concrete core. Then the results organized as equations or figures represent this relationship which is widely provided to any researcher deals with normal concrete strength. The information about this field in UHSC is very limited, since this type of concrete is relatively new type. Figure-4 will be adopted to determine the force-slip relationship of Combin39 element which was proposed in Ref. [14]. The values that tabulated in Table-3 represent the real constants of combin39 element.

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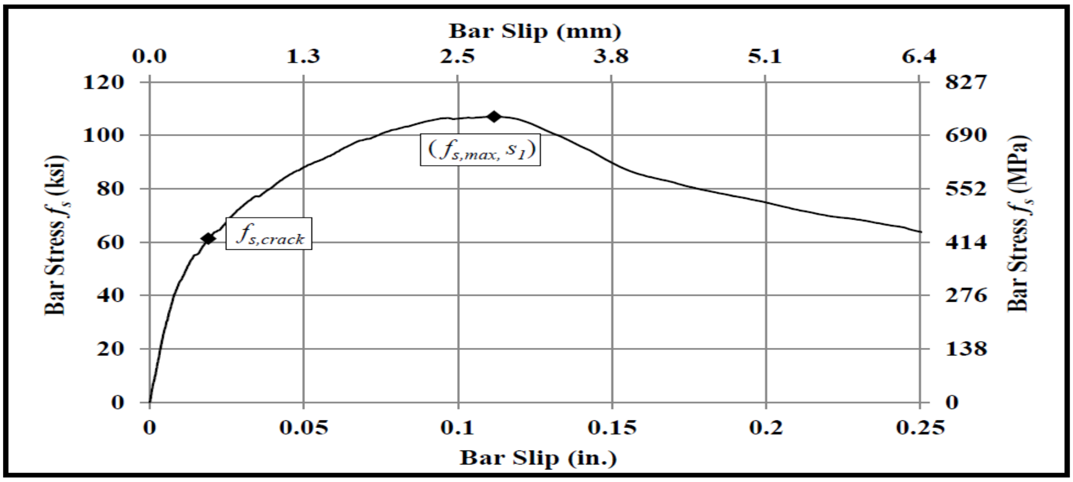

Figure-4. Typical bar stress versus slip curve for reinforcing bar in UHPC [14].

Table-3. Real constants of combin39 element.

12mm bar diameter main reinforcement	
Slip (mm)	**Force** (N)
0	0
0.18	18354
0.2	36708
0.45	55062
1.02	73416
1.9	91770
2.5	97843
3.25	91770
4.4	73416
5.1	68827
6.4	59921

3.2. Beams generation

As a first step the element types as well as their corresponding real constants and material properties were entered, then the beam with its real dimensions will be created by using the volume order. Dividing the volume into small size elements is a necessary step in finite element analysis, which should be done by meshing solid65 element type to simulate the UHSC beam and new nodes were be created through this step.

Link180 element were be used to create the top and stirrups reinforcement bars at the same nodes which shared the Solid65 element to represent a full bond between the both elements at the appropriate locations. The same procedure was used in creating the bottom reinforcement steel bars at the appropriate location for the non-spliced beam as well as the spliced beam, except in the splice region as it will be explained when discussing generation of Combin39 element.

A slip may occurs between the reinforcing bars and UHSC within the splice region if the splice length is not adequate in the splicedbeams. So the slip Combin39 element were be used to reflect this behavior only within the splice region. A new nodes have the exact coordinates of solid65 element nodes were be created in this region to generate the bottom bars by using Link180 elementals. These nodes which shared the same coordinates were be utilized to generate Combin39 made this element to be zero element. The X- direction slipping was chosen to be the slipping direction in this work.

By constraining the nodes in Y- direction the roller support was modeled while constraining the nodes in both X- and Y-directions the hinge support was modeled. To insure full simulation of the supports the rotational movement had been allowed in both cases. The two concentrated load was modelled by applied them on the base plate at the same locations as that was applied through the experimental work. Figures (5) and (6) illustrate the beamsUC-2-N and UC-2-10d modeling details, the load and supports representation respectively.

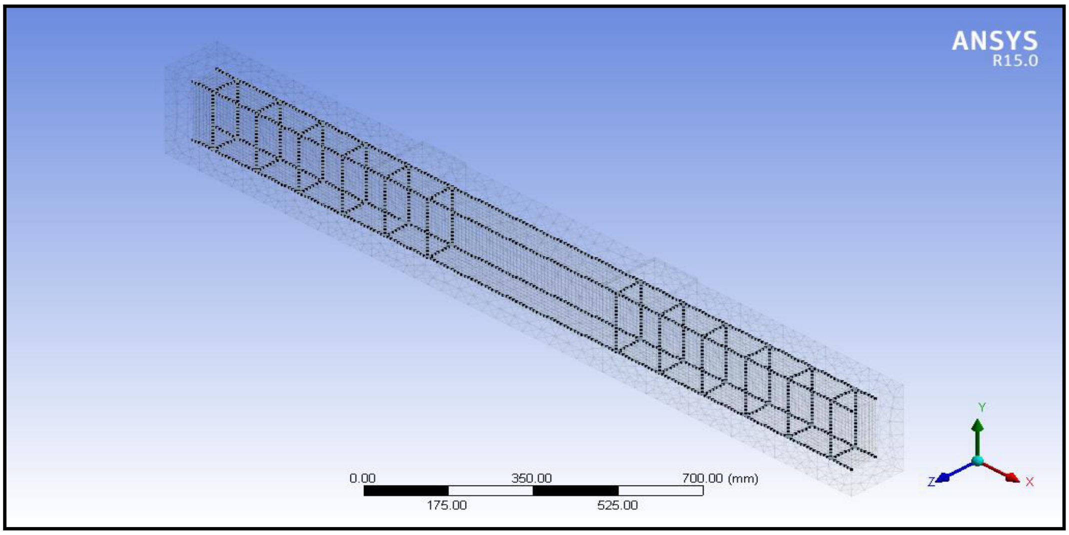

Figure-5. Beam UC-2-N modeling.

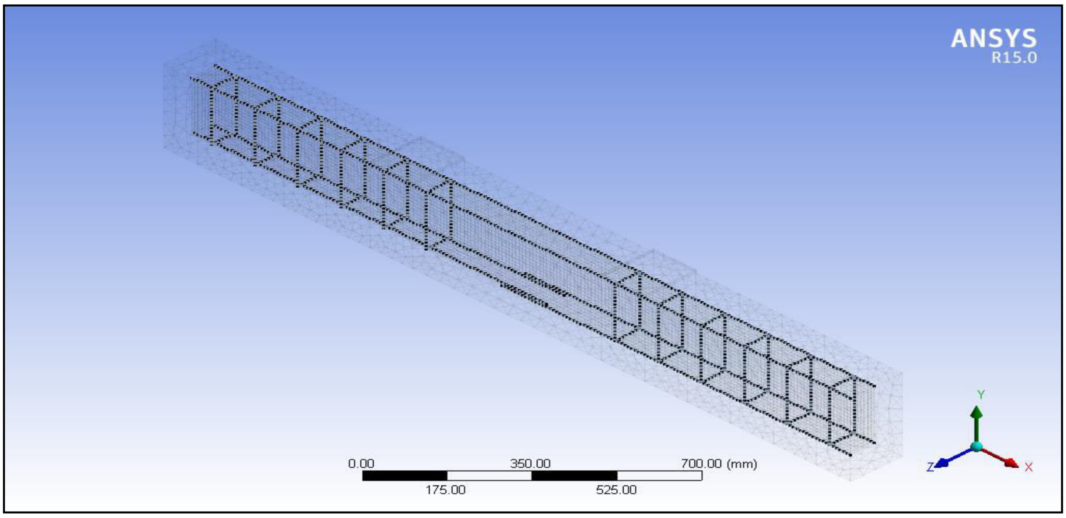

Figure-6. Beam UC-2-10db modeling.

3.3 Static analysis

The Static analysis type was used in analyzing these two beams. The applied load was divided in to ten load steps. Failure of the beam occurs when convergence fails, with this very small load increment.

Load-deflection curves from the theoretical analysis were plotted for both beams and compared with the experimental load deflection curves as shown in Figure-7. The ultimate load for both beams was 139.7kN according to the ANSYS analysis while this value was 140kN and 136kN approximately according to experimental work for beams UC-2-N and UC-2-10db respectively. The deflection at the ultimate load was 5mm and 6.8mm for beams UC-2-N and UC-2-10db respectively according to analysis work, but these values were 6mm and 5mm for the experimental work. These values indicate that the analytical results compared well to experimental results.

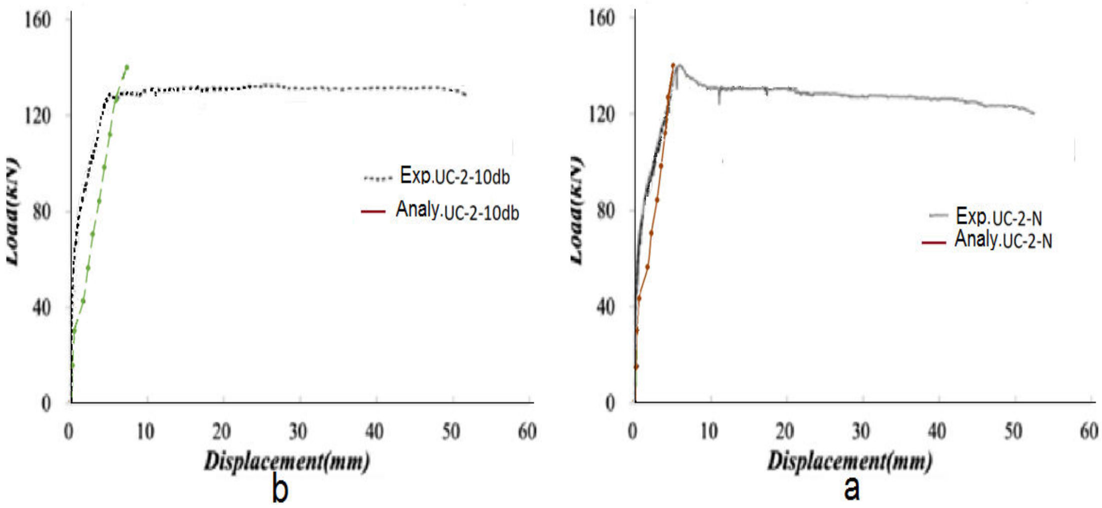

Figure-7. Analytical and experimental load deflection curves comparison in beams (a) UC-2-N and (b) U-C-2-10db.

4. PARAMETRIC STUDY

The goal of the comparison between the FE model and the experimental work which was done by Lee 2015 is to ensure that the elements, material properties and real constants are adequate to model the response of these members and this was assured as shown from the previous results. Thereafter nine beams with different lap splice length and steel fiber ratios were modeled to predict load deflection curve of each beam as attempt to enrich the analytical work and add extra information to the field concerns the effect of splice length and steel fiber ratio on the response of UHSC beams containing lap spliced flexural reinforcement. Table-4 illustrated the details of these beams.

Table-4. Beams of parametric study.

Beams	Lap splice		Vf%
	Length (mm)	Ls/db	
UC-1.5- N	-	-	1.5
UC-1.5-10db	130	10	
UC-1.5-15db	200	15	
UC-1-N	-	-	1.0
UC-1-10db	130	10	
UC-1-15db	200	15	
UC-0.5-N	-	-	0.5
UC-0.5-10db	130	10	
UC-0.5-15db	200	15	

Figure-8 demonstrates a comparative load-deflection curves from the analytical results of beamsUC-1.5-N, UC-1.5-10db and UC-1.5-15db.This comparison curves show that failure load of beams UC-1.5-N and UC-1.5-15db was 126.8kN and the corresponding deflection 4.6mm and 5.7mm, while it was 84kN for the beam UC-1.5-10db with corresponding deflection 3.8mm.The presence of lap splice with less length in beam UC-1.5-10dbforced the beam to collapse before approaching the ultimate strength of the beam UC-1.5-N but the higher length of lap splice in the beam UC-1.5-15db developed the required strength as for the non-spliced beam.

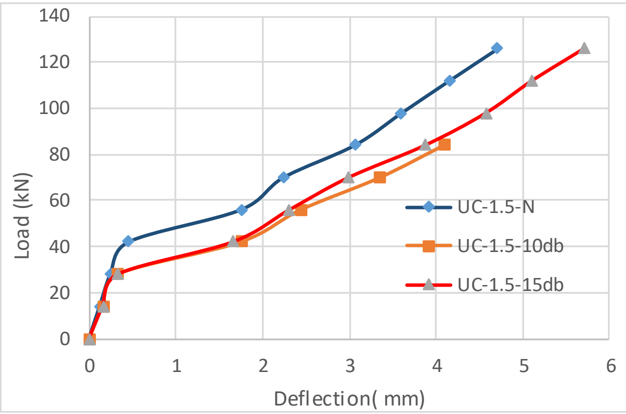

Figure-8. Analytical load deflection curves comparison for beams UC-1.5-N, UC-1.5-10db and UC-1.5-15db.

Figure-9 gathers the load deflection curves of UC-1-15db, UC-1-10d and UC-1-N, so a response comparison can be done between the three beams. It is obvious that the spliced beams UC-1-15d and UC-1-10d failed at load 56kN, so both beams did not reached the ultimate load of the non spliced beamUC-1-N which was 84kN. This response indicates that the lengths of lap splice were not adequate to develop the required strength of the non spiced beam with this value of steel fiber ratio which is 1%.

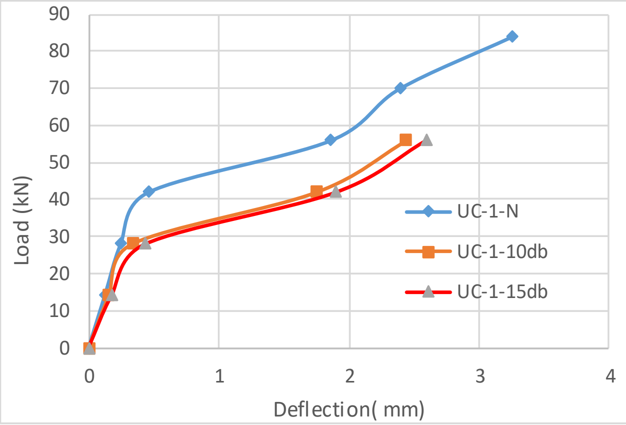

Figure-9. Analytical load deflection curves comparison for beams UC-1-N, UC-1-10db and UC-1-15db.

The load deflection curves of beams UC-0.5-15d, UC-0.5-10d and UC-0.5-N are shown in Figure-10. The failure load of both spliced beams was 56kN respectively, while the failure load of the non splice beam was 79kN with deflection of 3.6mm. The early failure of spliced beams relates to the splice failure as a result of short splice length in this case of steel fiber ratio.

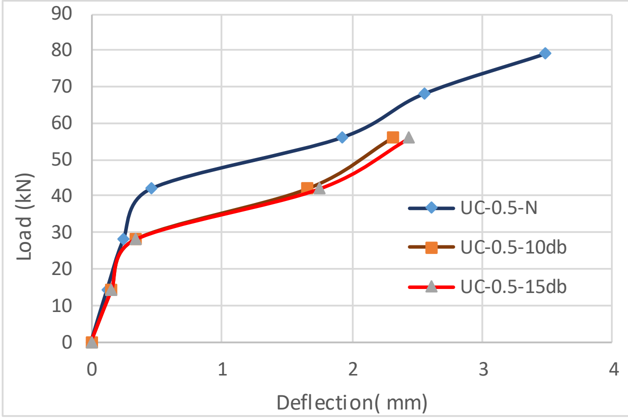

Figure-10. Analytical load deflection curves comparison for beams UC-0.5-N, UC-0.5-10db and UC-0.5-15db.

Figures (11 to 21) demonstrate the deflected shapes obtained from the analytical analysis of all analyzed beams at the failure load.

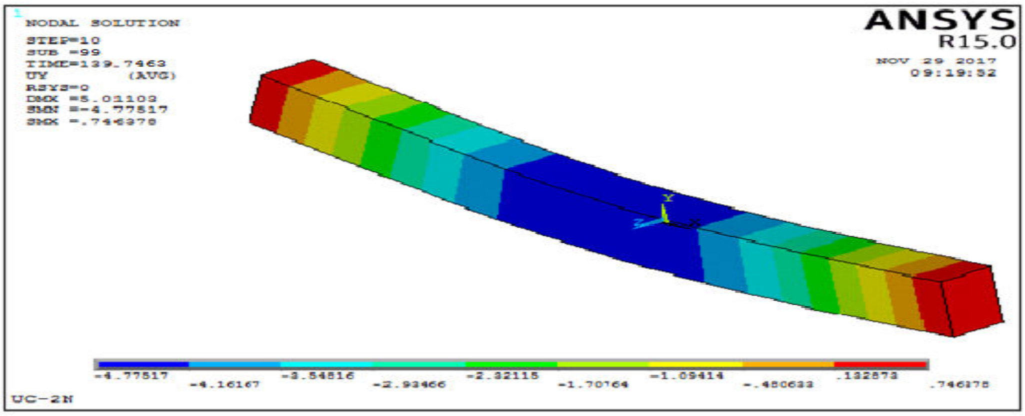

Figure-11. Deflected shape contour for beam UC-2-N.

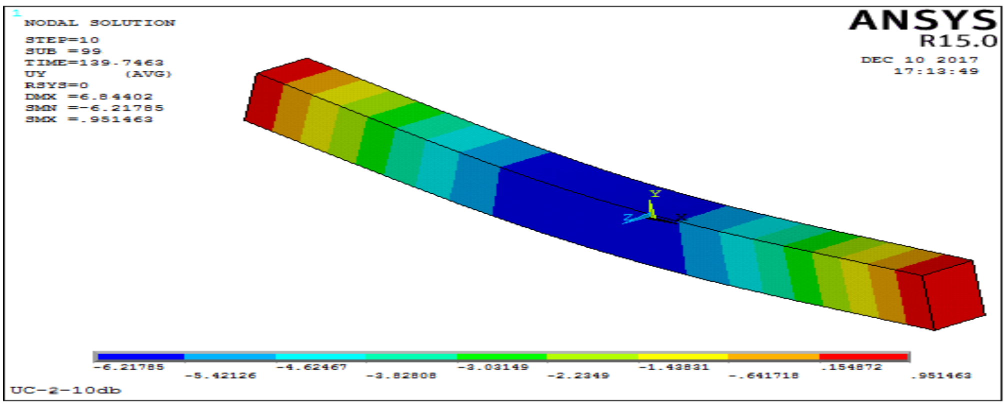

Figure-12. Deflected shape contour for beam UC-2-10db.

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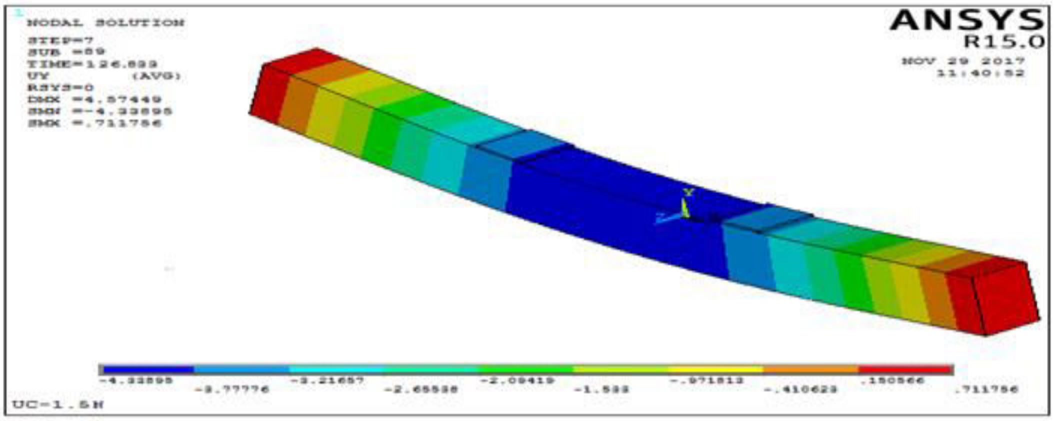

Figure-13. Deflected shape contour for beam UC-1.5-N.

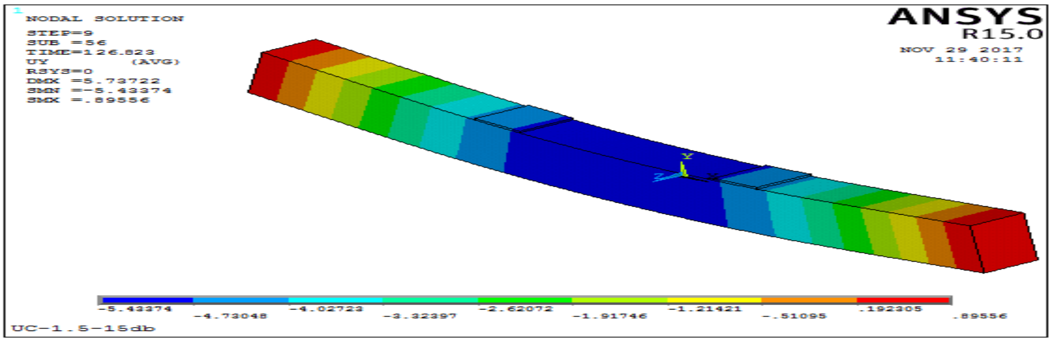

Figure-14. Deflected shape contour for beam UC-1.5-15db.

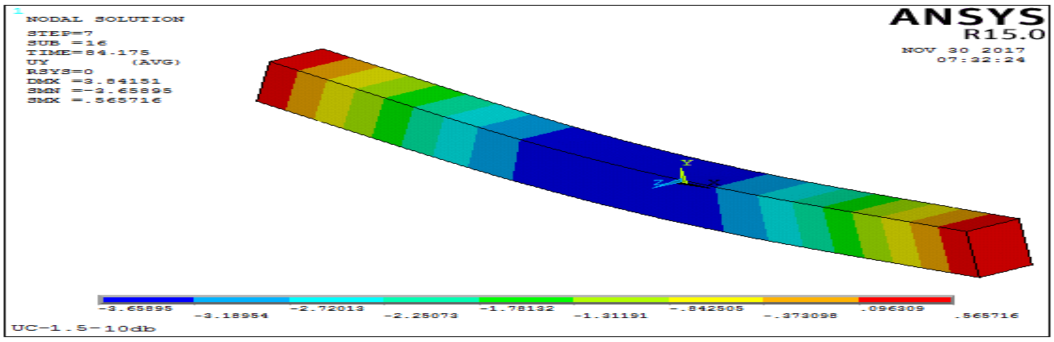

Figure-15. Deflected shape contour for beam UC-1.5-10db.

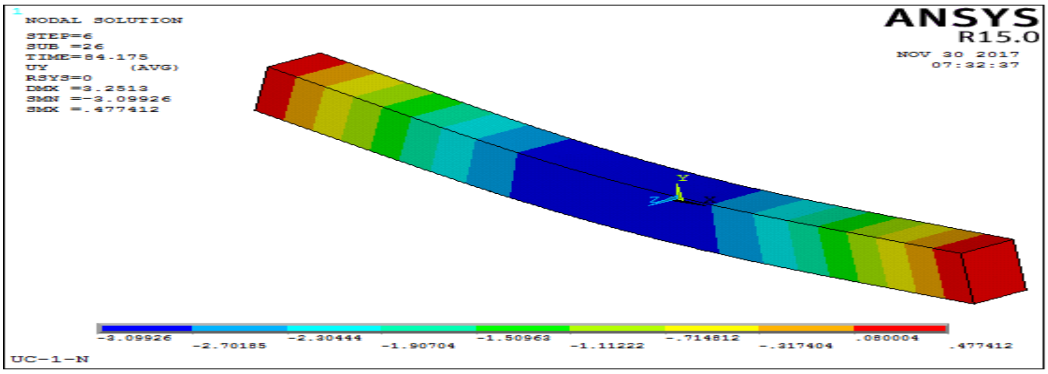

Figure-16. Deflected shape contour for beam UC-1-N.

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ARPN Journal of Engineering and Applied Sciences

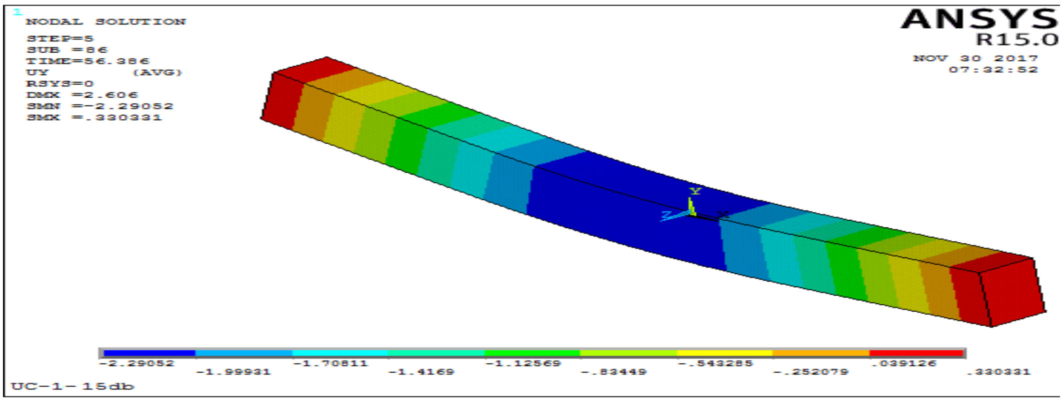

Figure-17. Deflected shape contour for beam UC-1-15db.

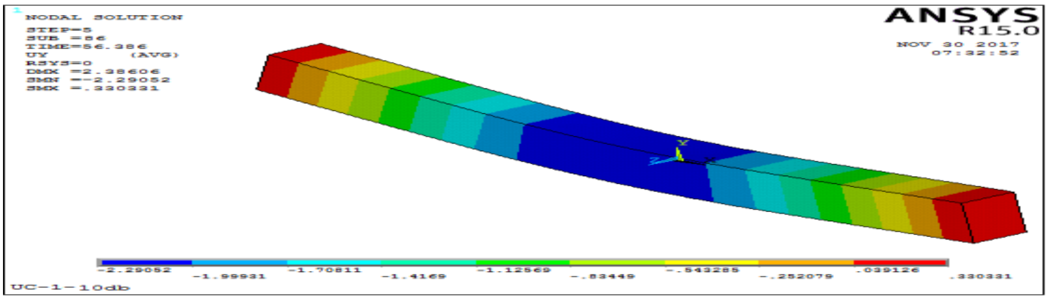

Figure-18. Deflected shape contour for beam UC-1-10db.

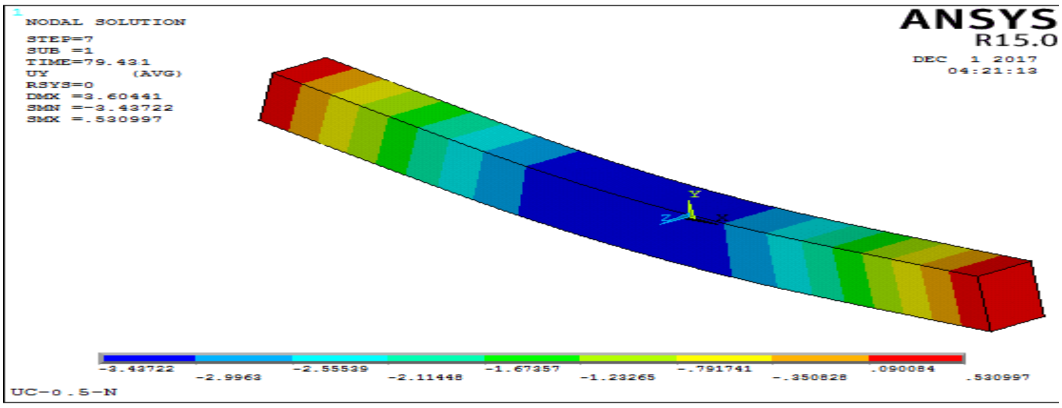

Figure-19. Deflected shape contour for beam UC-0.5-N.

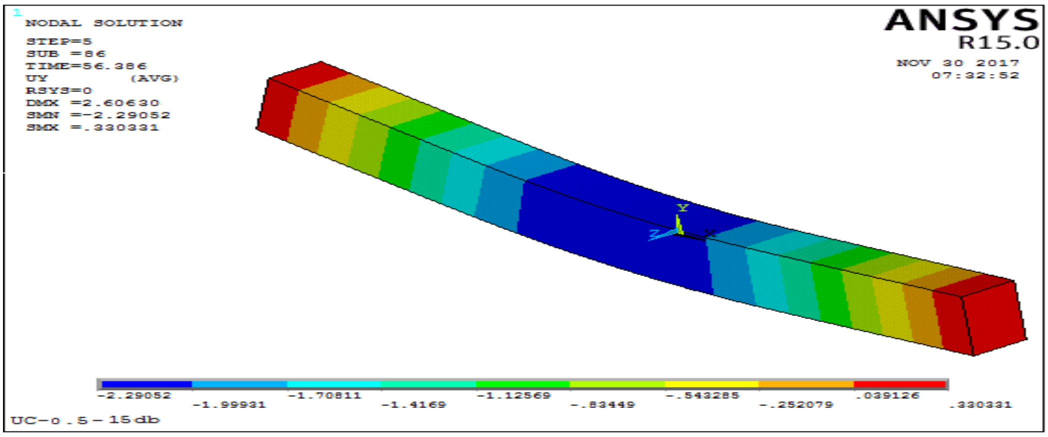

Figure-20. Deflected shape contour for beam UC-0.5-15db.

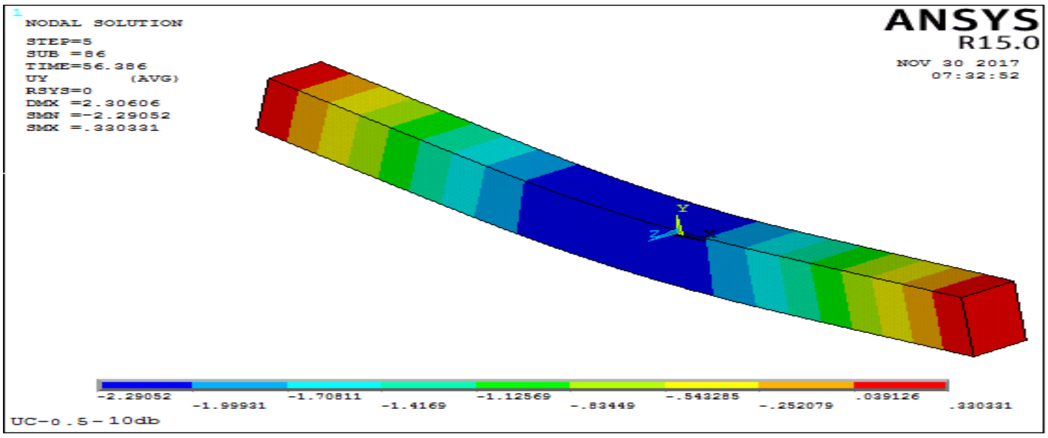

Figure-21. Deflected shape contour for beam UC-0.5-10db.

5. CONCLUSIONS

From the above analysis it can be concluded that:

a) The ultimate load and the corresponding deflection predicted from the analytical work compared well to experimental work obtained from a UHSC beam test. The average difference between the two works was 98% in failure load results, and it was 85% in deflection results.

b) The finite element model used in the numerical analysis was capable to simulate the load deflection behavior of lap spliced and non spliced UHSC beams, and this assured the validity of the proposed F.E model.

c) The parametric study which was performed within the analytical work resulted that the steel fiber ratio has a significant effect on the adequate lap splice length of lap spliced UHSC beam. Increasing the steel fiber ratio allowing decreasing the lap splice length and vice versa.

d) Within limits of this analysis study, it was obtained that 15 times diameter of bar is a sufficient lap splice length for UHSC beams if the steel fiber volumetric ratio did not decrease more than 1.5% when tested under monotonic load.

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